

# Level-Ice Melt Ponds in the LANL Sea Ice Model, CICE

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In a new melt pond parameterization developed for the LANL sea ice model CICE, the ponds evolve according to physically based process descriptions, accounting for the topography of the sea ice. Realistic model hindcast simulations (1958–2007) are used to explore the interactions of physical mechanisms that affect the evolution of ponds and sea ice albedo, highlighting the importance of snow melt processes and precipitation rates for trends in ice volume. Various feedback mechanisms also come into play, including a new level-ice-pond feedback that enhances the rate of sea ice thinning.

**S**urface characteristics determine the surface energy balance of sea ice. Sea ice volume is highly sensitive to the thermodynamic fluxes that determine this balance, of which short- and long-wave radiation are critical components in summer. Summer melt ponds, pools of melted snow and ice that collect in depressions on the ice surface, are relatively dark in color and can lower the surface albedo considerably from the relatively high values associated with snow cover and bare ice. The surface albedo continues to decrease as more melt water collects on the ice, increasing solar absorption and further melting the ice and snow, an important albedo feedback process. The formation, evolution, and disappearance of melt ponds are governed by complex processes, including interactions with the existing snow layer, drainage rates through permeable sea ice, episodic refreezing, and considerations of ice topography, making detailed melt pond modeling a daunting task.

A new melt pond parameterization has been developed for the LANL sea ice model, CICE [1]. The ponds evolve according to physically based process descriptions, assuming a depth-area ratio [2] for changes in pond volume. A novel aspect of the new scheme is that the ponds are carried as tracers on the level (undeformed) ice area of each thickness category, thus limiting their spatial extent based on the simulated sea ice topography. This limiting is meant to approximate the horizontal drainage of melt water into depressions in ice floes. Infiltration of the snow by melt water postpones the appearance of ponds and the subsequent acceleration of melting through albedo feedback, while snow on top of refrozen pond ice also reduces the ponds' effect on the radiation budget. Other simulated melt pond processes include collection of liquid melt water and rain into ponds, drainage through permeable sea ice or over the edges of floes, and refreezing of ponds [3].

Melt ponds first appear at southerly latitudes in spring, moving north as the melt season progresses (Fig. 1). Ponds form quickly and are

widespread initially, then pool into low topographic features and begin to drain through permeable ice within a few weeks. Pond area then slowly increases due to continuing snow and ice melt until the ponds' upper surfaces begin to refreeze. Because of variations in topography and permeability, we find deeper ponds on thicker, more deformed ice, and these are the last to freeze over in autumn.

Interannual variability is significant throughout the simulations, driven by three non-climatological forcing fields: air temperature, humidity, and wind velocity. Feedback processes are important for strengthening the variability. These include the ice-albedo feedback, in which changing ice surface characteristics enhance or reduce melting, and the ice-ocean albedo feedback in which reduced ice cover reveals the darker ocean surface, allowing greater heat absorption and additional ice melt; the ice-ocean albedo feedback also works in reverse, with increased ice area leading to ocean cooling and further ice formation. In this study we discovered a level-ice-pond feedback mechanism that has not been described previously, in which thinning ice has more level surface area available to be covered in ponds, enhancing thinning.

Sensitivity tests reveal that the snow simulation is critical, because the volume of snow deposition and rate of snow melt largely determine the timing and extent of the simulated melt ponds. Nevertheless, compensating effects moderate the model's sensitivity to precipitation changes. For instance, infiltration of the snow by melt water postpones the appearance of ponds and the subsequent acceleration of melting through albedo feedback, while snow on top of refrozen pond ice also reduces the ponds' effect on the radiation budget. With less snow insulating the ice (in more recent years), we would expect greater conduction and sea ice growth in winter, but increased radiation penetrating the ice slows growth and/or enhances summer melting, leading to thinner sea ice overall.

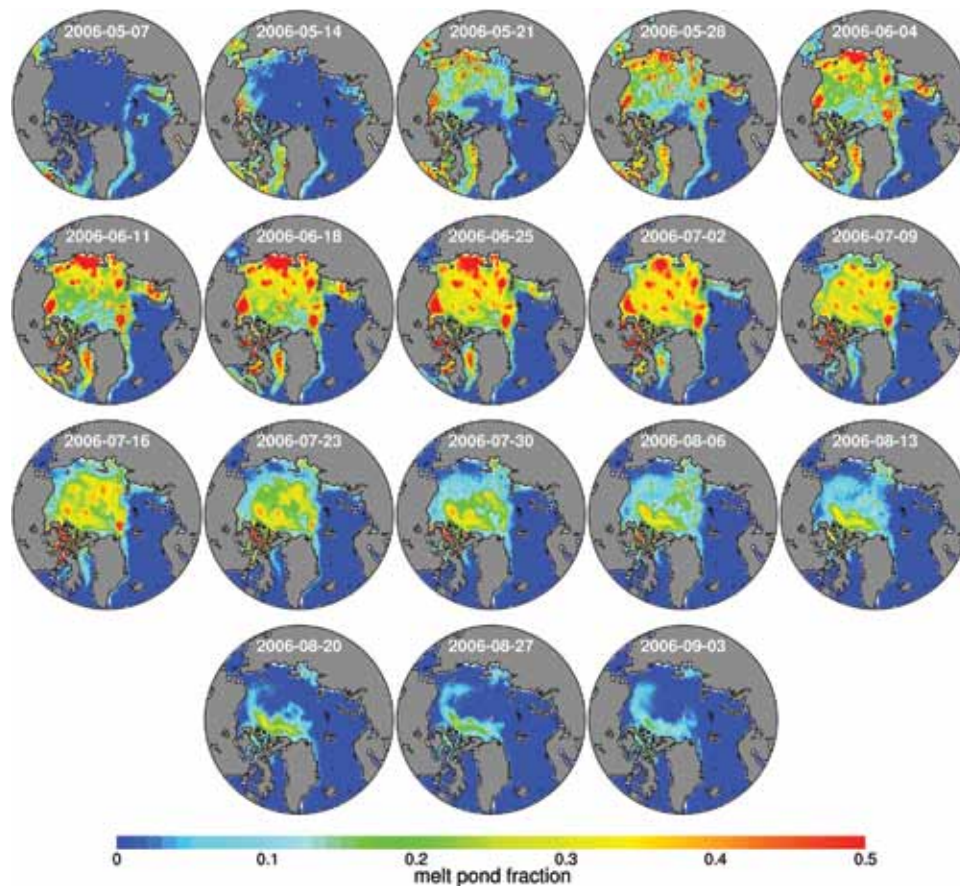
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Fig. 1. Ponded fraction of ice area, simulated for the Arctic in 2006.



[1] Hunke, E. et al., "Level-ice Melt Ponds in the Los Alamos Sea Ice Model, CICE," LA-UR 12-21874; *Ocean Model*, in revision (2012).

[2] Holland, M.M., et al., "Improved Sea Ice Shortwave Radiation Physics in CCSM4: The Impact of Melt Ponds and Aerosols on Arctic Sea Ice," LA-UR 11-10223; *J Clim* **25**, 1413 (2012).

[3] Flocco, D. et al., "Impact of Melt Ponds on Arctic Sea Ice Simulations from 1990 to 2007," LA-UR12-21872; *J Geophys Res* doi:10.1029/2012JC008195, in press (2012).